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SPECTRAL MONITORING OF ROCKET FLAMES

By

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21 July 1966

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This report describes work accomplished under WEPTASK R-360FR108(S), Spectral Monitoring of Rocket Flames.

Mr. F. D. Stork, Head, Propulsion Branch; Mr. A. T. Dixon, Head, Launcher and Propulsion Division; and Mr. R. H. Peterson, Head, Laboratory Department, have reviewed this report for publication.

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SUMMARY

Three types of spectrographs suitable for analysis of rocket flames are described, together with typical spectrograms of various rocket and pyrotechnic flames. The usefulness of flame spectra in rocket evaluation is discussed.

INTRODUCTION

In the preflight evaluation of air-launched rocket motors, a constant and pressing problem is that of obtaining an absolute maximum of information from a minimum number of firings. This problem results from the high cost of test samples, and the high level of confidence required in order to certify a new design as safe for air launching. A similar problem is encountered a few years later when the age limits of the motors must be established as accurately as possible. At both stages, spectral analysis of the rocket flame can add much to the information obtained in static firings at little additional cost. For this reason, preliminary investigations into the types of technique and instrumentation involved have been conducted at the U.S. Naval Missile Center. These investigations have been conducted under the Foundational Research Program, WEPTASK R-360FR-108(S), and later under the SPARROW III missile program, WEPTASK RM-372P-232 (Problem Assignment 2).

Specifically, the spectral analysis of rocket flames can be expected to be valuable in the following ways:

1. By providing detailed information on the ignition phase, it can furnish a mathematical basis for estimating ignition reliability, without resorting to the mass testing of 1,000 or more rockets.
2. The intensity of certain spectral lines versus time will provide a check on the uniformity with which the propellant was mixed. Any undue concentration of fuel, oxidant, burning-rate catalyst, etc., will produce a corresponding peak in the intensity of the spectral lines involved.
3. Many forms of incipient failure, such as excessive erosion of thermal insulation materials, etc., can be detected, and corrective action taken, in those cases where actual failure did not occur.
4. The age limits of prepackaged liquid rockets can be established with increased reliability by determining the concentration of corrosion products in the exhaust in the course of the usual surveillance firings. This can be done at little additional cost, and without consuming additional test samples.
5. In radio frequency (RF) attenuation studies, flame spectroscopy is useful in detecting those accidental impurities (such as alkaline earth metals) which aggravate the attenuation problem.

OBJECTIVE

The objective of this work was to establish the feasibility of recording the spectra of rocket flames in static firing tests, and to illustrate the usefulness of these spectra in serving the above purposes.

BACKGROUND

Spectrochemical analysis is based on the fact that the spectrum of a heated mass of gas or vapor contains discrete lines and bands, whose positions and intensities are unique to the atoms, ions and molecules (or other polyatomic groups) present. These lines and bands are either brighter or darker than the background (or continuum) radiation, according to conditions. In the main, sharp lines are unique to the elements present, while bands are attributable to the molecules or polyatomic "species" present (such as AlO , SrOH , etc.). Most of the atomic lines and many molecular bands are listed in published tables according to position and intensity. The number of lines tabulated for a given element varies widely (from 2 lines for polonium to 5,755 lines for cerium). Their intensities also vary widely (from 1 to 9,000 on an arbitrary scale). Intensity figures cannot be accurately equated to energy values, since they are only relative values obtained photographically.

The specificity of observed spectral lines (i.e., their reliability as criteria of the presence of specific elements or species) is a function of four factors:

1. Accuracy of wavelength measurement.
2. Intensity.
3. Contour of line (i.e., whether it shades to higher or lower wavelengths).
4. Coexistence of other lines tabulated for the same element or species.

The specificity of a given spectrum depends greatly on the instrument used. The accuracy of wavelength measurement for a good laboratory spectrograph is approximately $\pm 0.1 \text{ \AA}$, although wavelength tables read to 0.001 \AA . A statistical analysis of typical data from the P5b instrument indicated a standard deviation of $\pm 8 \text{ \AA}$. The low accuracy is largely due to the crowding of a wide spectral region onto a narrow photographic film. It must be kept in mind that this lack of accuracy in a rocket flame spectrum can be eliminated in most cases by preparing laboratory spectra of the rocket components, thus obtaining accurate wavelength values for the same lines.

Contour is of little use in identifying spectral lines, as very few lines shade off in one direction or the other. In identifying band spectra, however, contour is quite useful, as many bands shade to high or low wavelengths.

Coexistence and relative intensities are useful in analyzing flame spectra provided that film sensitivities are kept in mind.

TECHNICAL APPROACH

The approach used in this project was:

1. Select the spectrographic instruments most likely to yield meaningful data under rocket test pit conditions.

2. Calibrate the selected instruments, using suitable sources of atomic spectra.
3. Obtain spectrograms of typical pyrotechnic items and rockets of known chemical composition.
4. Identify as many elements and species as possible in the spectrograms obtained.

In selecting the instrumentation for this project, the resume of photo-optical methods included in reference 1 was of great help. This resume gives the advantages and disadvantages of a wide variety of instruments and systems. The emission spectrograph was selected as a basic instrument, because of its excellent specificity and its applicability to the relatively opaque flames produced by many types of rockets.

Photographic recording was used because instruments employing photographic recording were readily available at reasonable cost. Attempts were made to observe the spectrum with an image orthicon television camera, but the sensitivity of the best available camera was too poor to record the fainter spectral lines.

The specific instruments used on this project were as follows:

1. The wedge interference filter. This is an interference filter built with a varying distance between its elements, resulting in a filter with a varying peak transmission along its width. This device has sometimes been employed in spectral studies, and because of its simplicity and low cost, was tested for applicability to this study. Figure 1 shows a spectrogram of the mercury lamp photographed through a wedge interference filter. Since the best obtainable spectrogram showed only four lines, compared to 20 or more lines detectable by prism or grating spectrographs viewing the same source, the wedge interference filter was ruled out as too insensitive.

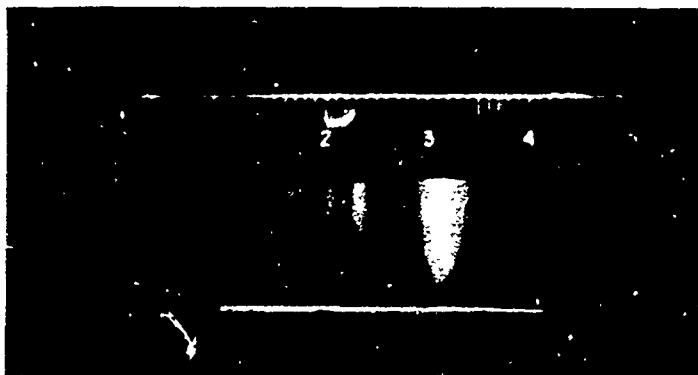


Figure 1. Mercury Spectrum Photographed Through a Wedge Interference Filter.

2. The Vought Spectral Camera. This is a streak spectrograph having a range of 1,800 to 8,000 Å (figure 2). Film limitations restricted its use to the range from 3,000 to 7,000 Å.
3. A local modification of the Vought camera, using the front-end optics of the Vought camera in conjunction with the film transport system from a gun camera (figures 3 and 4).

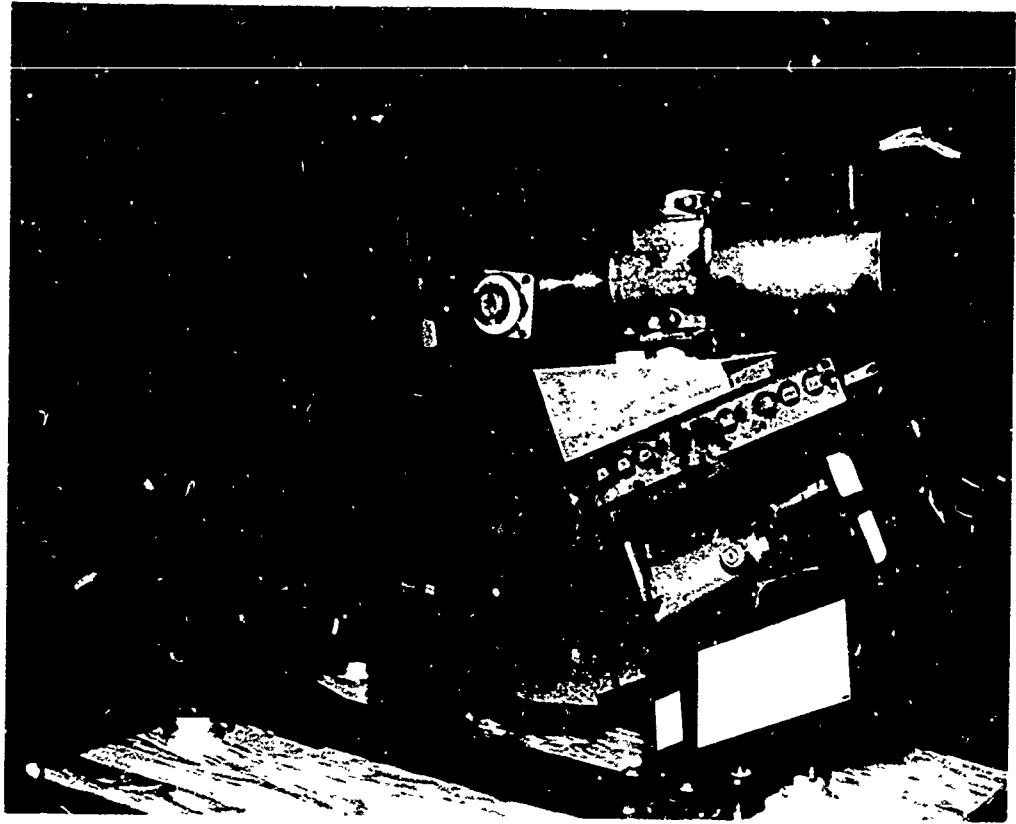


Figure 2. Vought Spectral Camera.



Figure 3. Naval Missile Center Modification of Vought Spectral Camera.

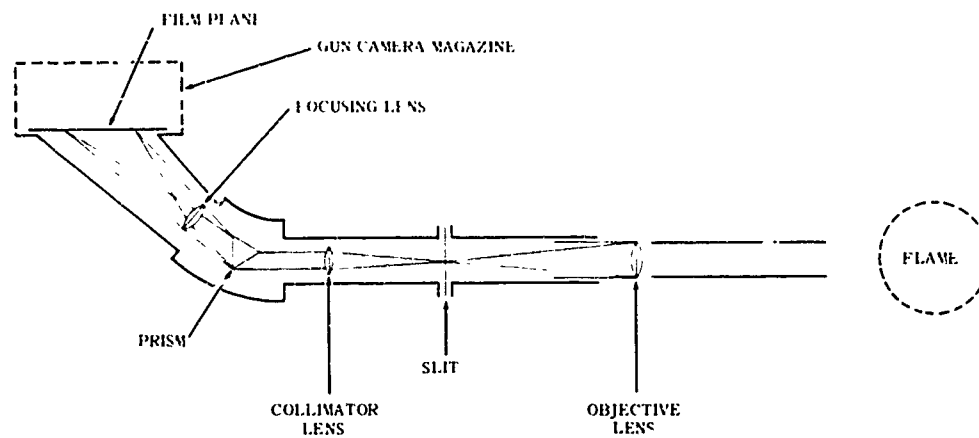


Figure 4. Schematic Diagram of Modified Vought Spectral Camera.

4. A locally-developed grating spectrograph designed by the Naval Missile Center Photographic Department. This instrument has a range of 3,000 to 7,000 Å (figures 5 and 6).
5. The Aerojet-General P5b ultraviolet cinespectrograph. This is a framing spectrograph having a range of 2,500 to 5,000 Å (figure 7).

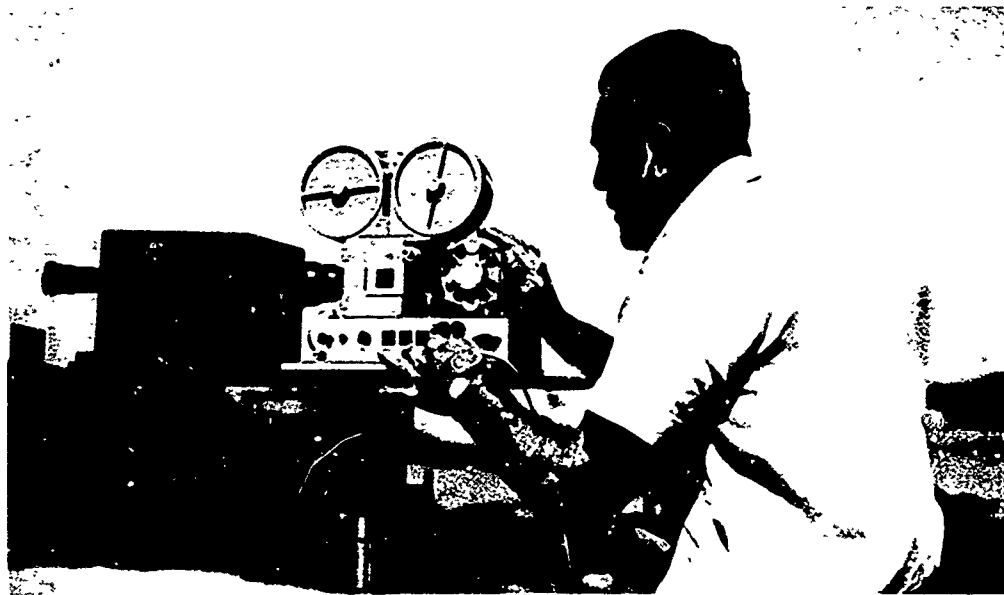


Figure 5. Naval Missile Center Grating Spectrograph.

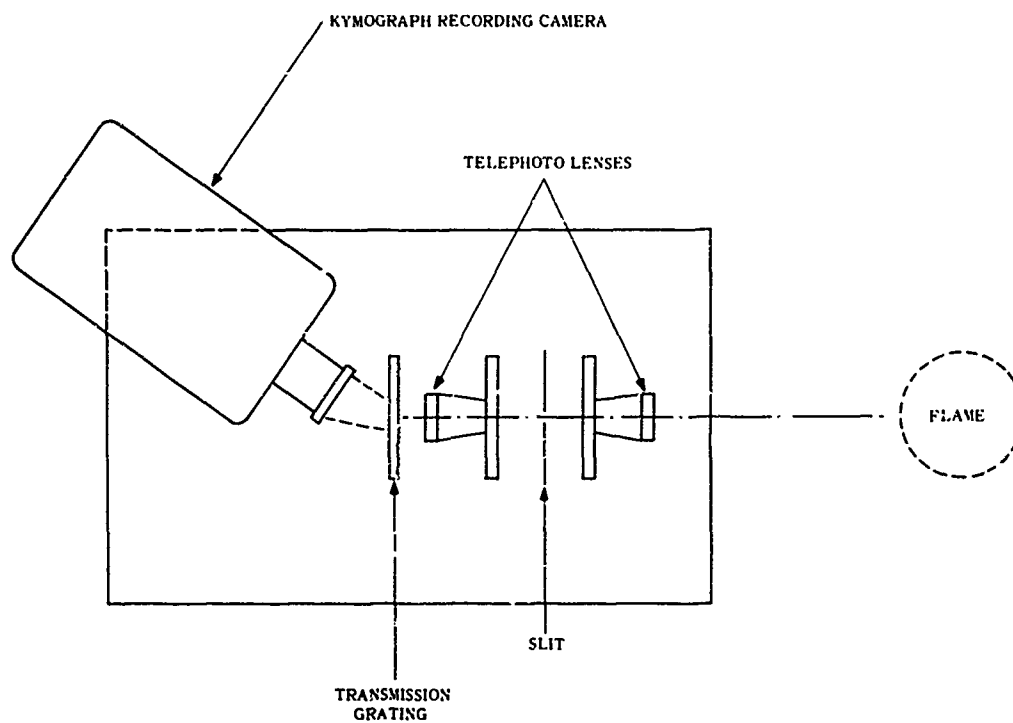


Figure 6. Schematic Diagram of Naval Missile Center Grating Spectrograph.

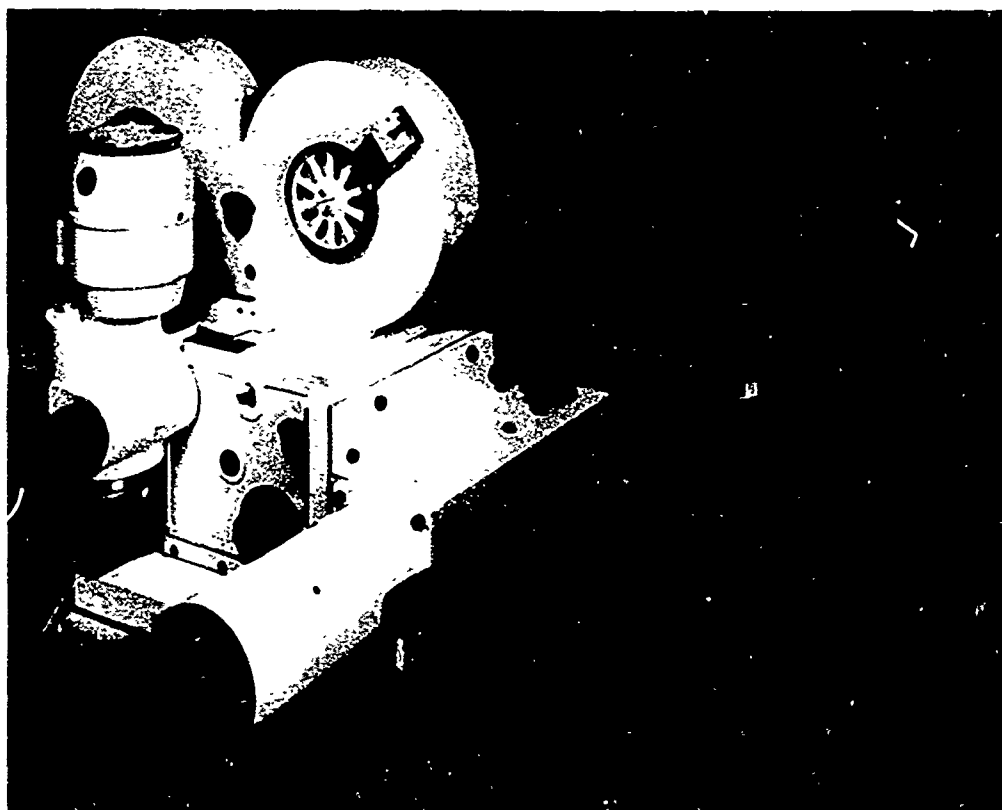


Figure 7. Aerojet-General P5b Ultraviolet Cinespectrograph.

DESCRIPTION OF TESTS

Spectrograms were obtained by placing the spectrograph at a distance of 5 to 50 feet from the flame being observed, according to the degree of explosion hazard involved. The spectrograph was placed on the windward side of the flame in order to avoid or minimize smoke interference. In each case, the spectrograph was started before the rocket or flare was fired, and kept running continuously until burning stopped. In one instance where a tracking flare was used as a flame source, the iris of the spectrograph was opened and closed during the firing. The spectrograph was aimed at different parts of the flame in different tests. The spectrogram of the red distress flare was analyzed on an Ansco microdensitometer.

REVIEW OF RESULTS

A review of the results thus far obtained (shown in figures 8 through 16) indicates the following:

1. Many elements present in rocket and pyrotechnic flames can easily be identified spectroscopically. The typical spectral lines of sodium, aluminum, strontium, chromium, potassium and lead have been identified in the Naval Missile Center studies. In addition, polyatomic species such as CuCl , SrOH , etc., have been identified.
2. The igniter flame of a solid rocket is clearly distinguishable from the propellant flame; likewise, in a packaged liquid rocket, the sporadic appearance of corrosion products can be clearly detected by the spectral lines of the metals involved.



Figure 8. Spectrum of Red Distress Flare.

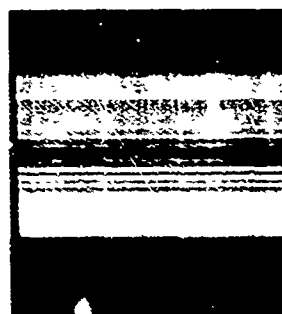


Figure 9. Spectrum of CROW Solid Ramjet Flame.

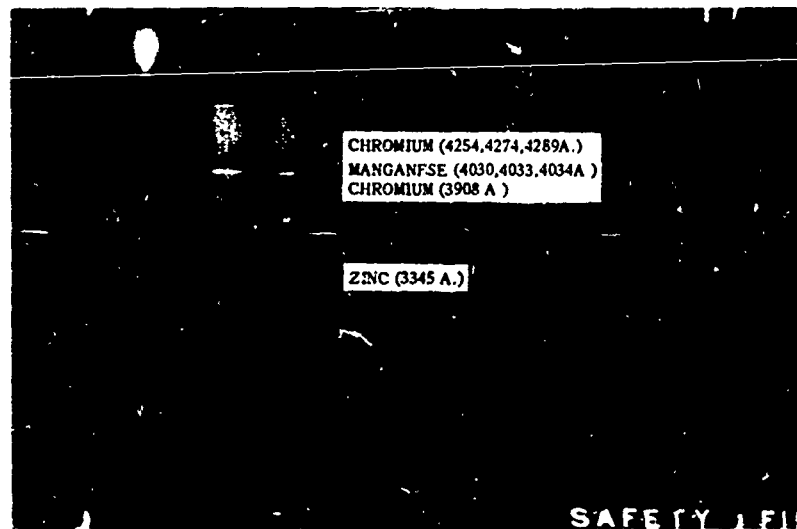


Figure 10. Rocket Flame Spectrum Showing Presence of Corrosion Products Due to Aging.

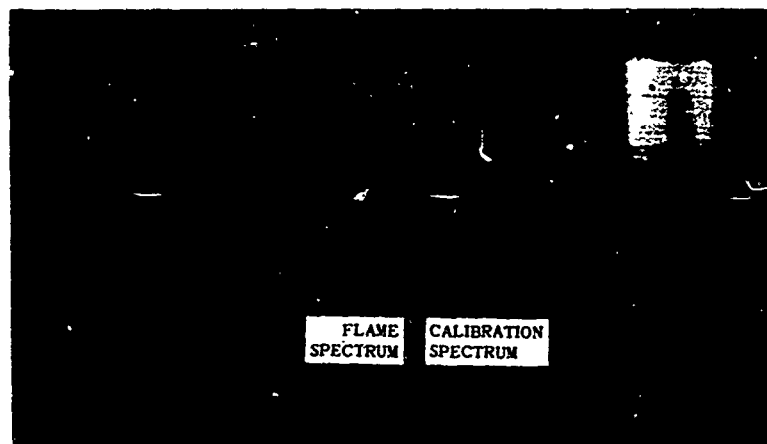


Figure 11. Flame Spectrum of Rocket Taken at Nozzle Exit. (From SPARROW III test.)

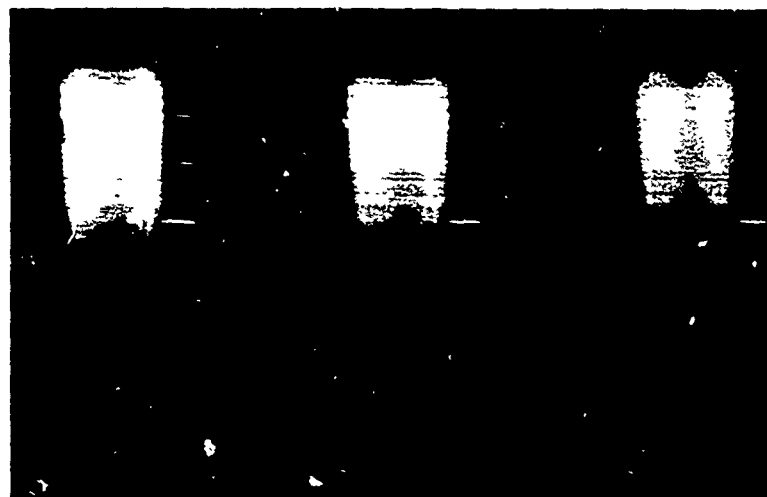
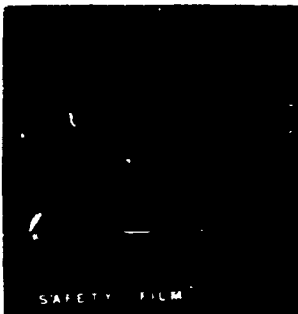


Figure 12. Spectrum of Same Type Rocket as in Figure 11, Taken 2 Feet Aft of Nozzle. Note wide bands of polyatomic species.



(a) POTASSIUM (VOUGHT CAMERA)



(b) RUBIDIUM (NAVAL MISSILE
CENTER SPECTROGRAPH)



(c) MERCURY-CADMIUM (VOUGHT CAMERA)

Figure 13. Calibration Spectrograms.

3. In a normal solid rocket flame, the atomic lines are clearly seen at the nozzle exit, and the polyatomic bands appear farther downstream. In some rockets having low-burning rates due to environmental damage, the polyatomic species appear closer to the nozzle, possibly because the over-all flame structure is shortened.
4. Photographic recording has some drawbacks and limitations but is the only type of recording available at a reasonable cost at the present time.

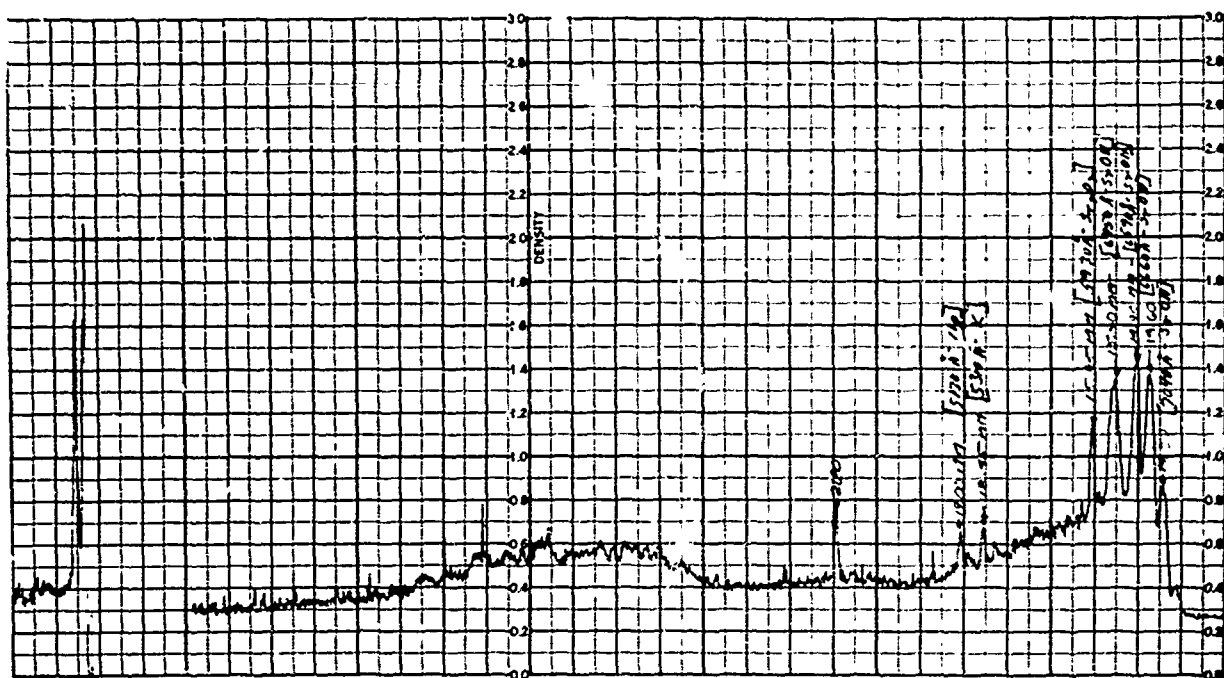


Figure 14. Microdensitometer Trace of Spectrum of Red Distress Flare.



Figure 15. Flame Spectrum of Solid Rocket Showing Wide Bands of Polyatomic Species.

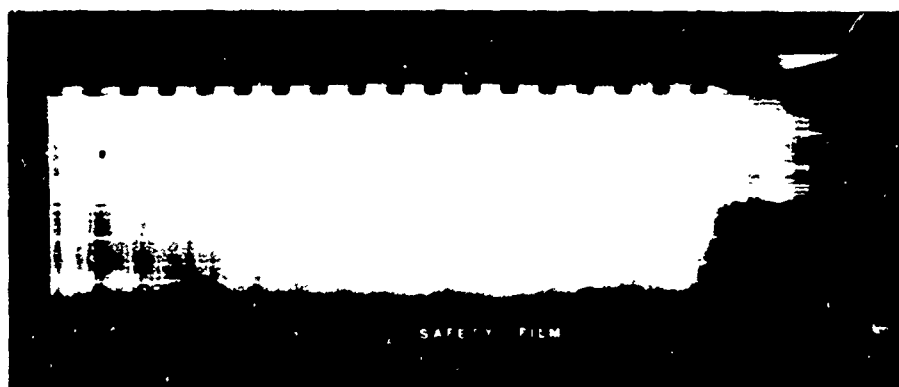


Figure 16. Flame Spectrum of Tracking Flare With Varying Iris Openings.

CONCLUSION

It is concluded that the feasibility and usefulness of spectral monitoring of rocket and pyrotechnic flames has been established, and that a greater capability for such monitoring should be developed.

REFERENCE

1. Melnechuk, Theodore. "Tools for Analytical Chemistry," International Science and Technology. Aug 1962.

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13. ABSTRACT <p>The purpose of this work was to develop a method of monitoring the uniformity of rocket propellant, the reliability of the ignition process, and the presence of accidental impurities and corrosion products by continuous spectrographic analysis of the rocket flame. A number of solid and liquid rocket flames and pyrotechnic flames were observed with three types of spectrographs. The spectral lines of numerous elements were identified. It is concluded that the technique is feasible and useful, and that a greater capability for spectral monitoring should be developed.</p>		

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